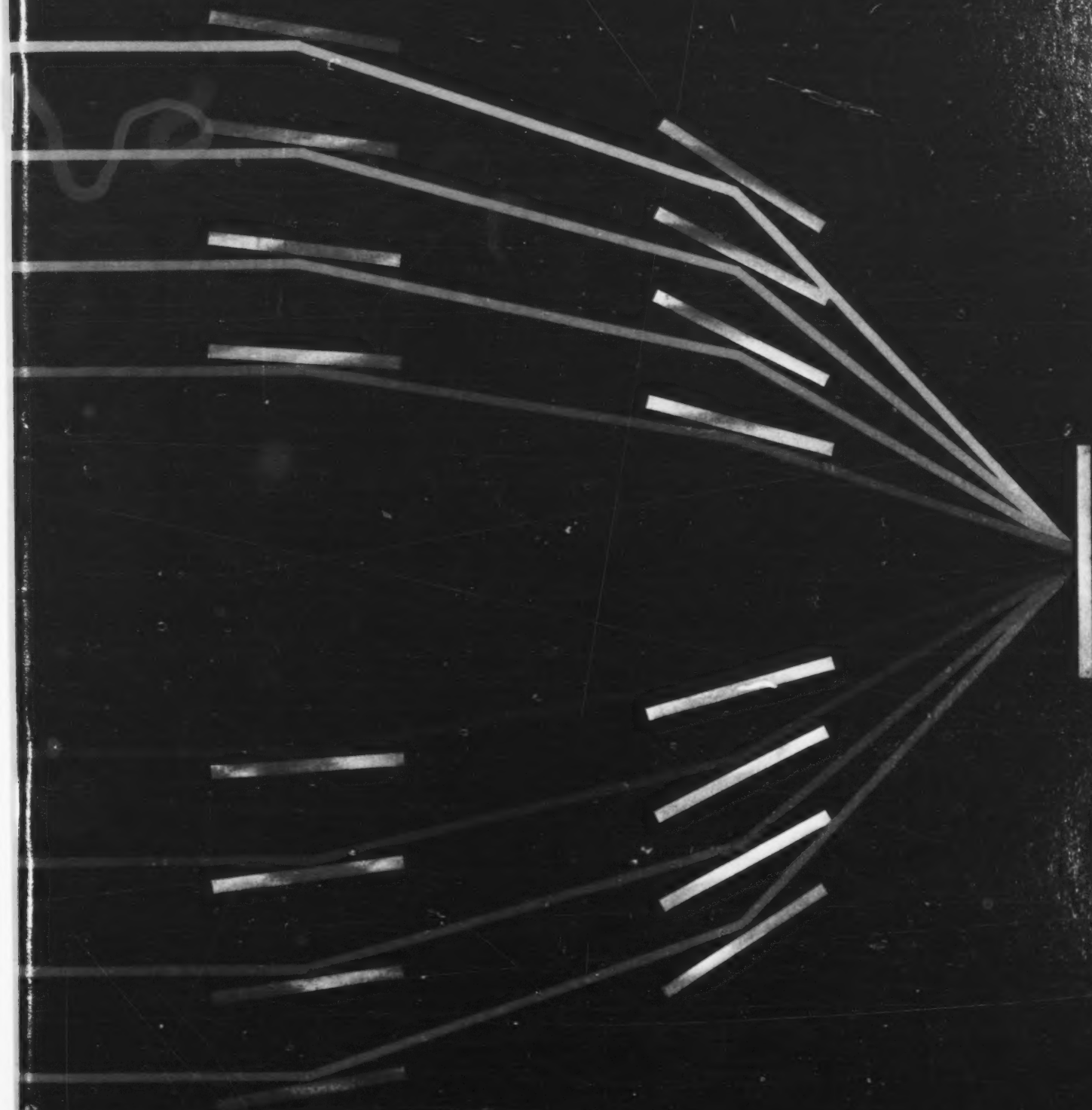


HIGH ENERGY ASTRONOMY OBSERVATORY



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National Aeronautics and
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FOREWORD

Since the launch of the second High Energy Astronomy Observatory HEAO 2, on November 13, 1978, a steady stream of pictures of the universe in X-ray light has been returned to eager astronomers and astrophysicists around the world.

X-rays from astronomical bodies cannot be seen by ground-based astronomers because Earth's own atmosphere blocks out this radiation. Only

instruments located above this obscuring layer can reveal the incredible richness of the X-ray sky.

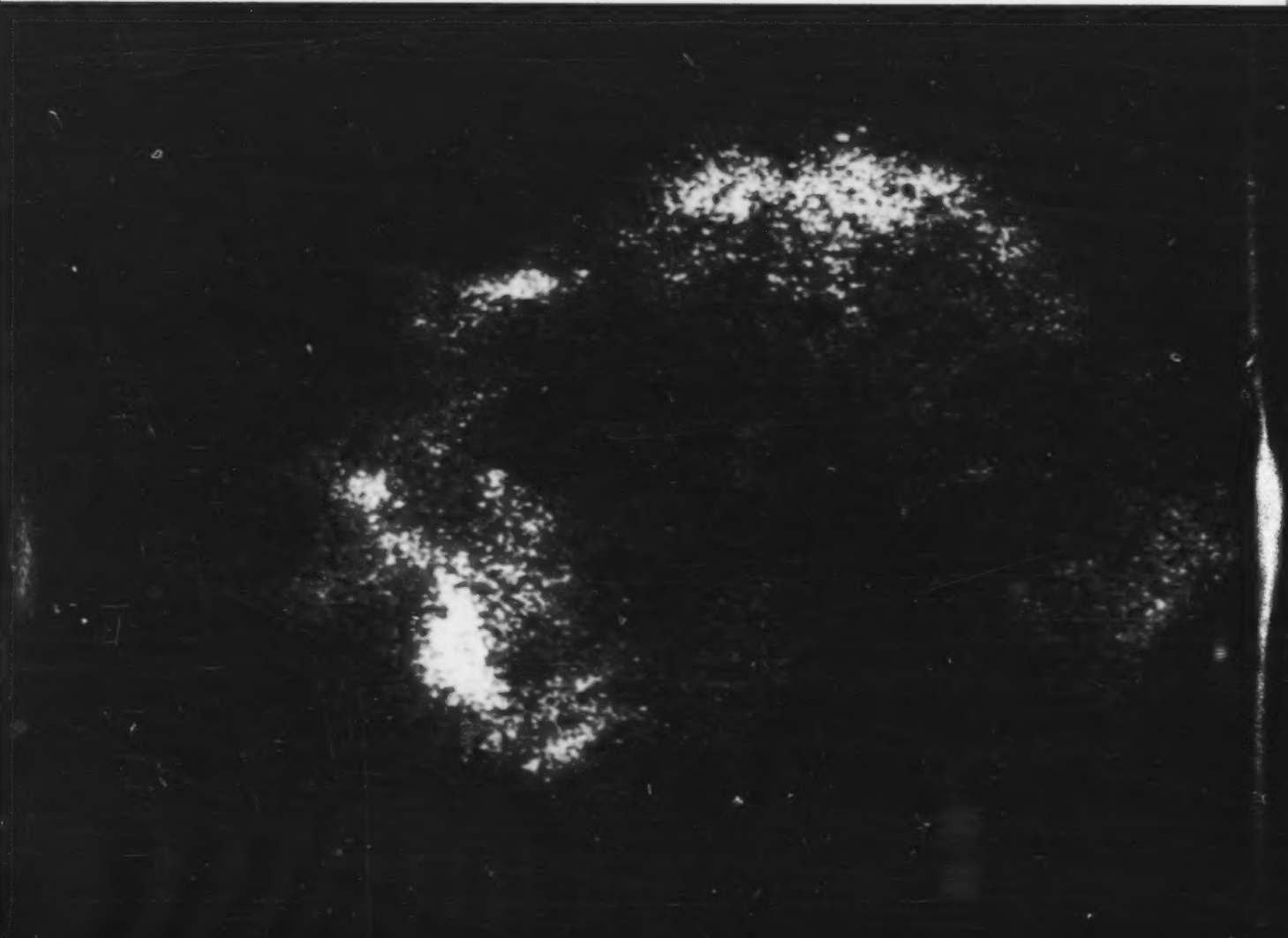
High energy radiation is associated with some of the strangest objects in the sky: neutron stars, exploding galaxies, the remains of supernovae, pulsars, cosmic bursters, and of course, black holes. This means the X-ray eyes of HEAO see a violent, turbulent uni-

verse still in evolution. It is a view that, along with optical and radio observations, overturns age-old conceptions of constant, permanent, immutable stars.

X-ray astronomy itself is a young, dynamic field in which most discoveries have come only during the last decade. HEAO 2, sometimes called the Einstein Observatory, represents a landmark in the development of this field,

for, unlike previous detectors carried by rockets and other satellites, its telescope provides focused pictures of these X-ray objects. With this instrument, X-ray astronomy has come of age, providing astronomers with a view comparable to the very best visible light and radio-wave pictures of the sky. HEAO 2 has surely opened a new window on the universe.

In addition to their sci-



entific importance, the pictures from HEAO are also intrinsically beautiful. This book is intended to share with you this new look at the heavens.

Robert A. Frosch,
Administrator
National Aeronautics and
Space Administration

X-Ray Image of Cassiopeia A Supernova remnant.

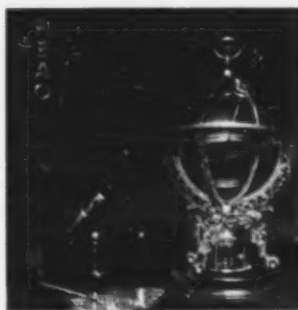
ACKNOWLEDGEMENTS

The HEAO-2 (Einstein) Observatory's scientific program is operated for NASA by a consortium that includes the Harvard-Smithsonian Center for Astrophysics, MIT's Center for Space Research, Columbia University, and the Goddard Space Flight Center. The principal scientists are George Clark of MIT, Robert Novick of Columbia, Stephen Holt of Goddard, and Harvey Tananbaum of Harvard-Smithsonian. Riccardo Giacconi of the Harvard-Smithsonian Center is the Principal Investigator with overall scientific responsibility for the program. Leon Van Speybroeck of the same institution, designed the telescope optics.

Hardware support for the imaging instruments

was provided by American Science and Engineering. The HEAO spacecraft were built by TRW, Inc. Project management was by the NASA-Marshall Space Flight Center with Fred Speer as Project manager.

Grateful recognition is made of the contributions by Richard Halpern, the HEAO Program Manager at NASA Headquarters; the Atlas-Centaur launch vehicle team at the Lewis Research Center; the HEAO launch operations team at the Kennedy Space Center; the flight control team at Goddard Space Flight Center; and the editors of this publication, James Cornell of the Harvard-Smithsonian Center for Astrophysics, and Wendell Johnson and Carroll Dailey of Marshall Space Flight Center.



INTRODUCTION



Astronomy was the first science. Archaeological evidence now shows that humans have always had a desire and a need to observe, study, and understand the heavens. More than 30,000 years ago, Cro-Magnon man scratched records of the Moon's phases on chunks of bone and deer antler. The megalithic builders of prehistoric Britain apparently designed Stonehenge as a giant observatory for marking the

seasonal motions of Sun and Moon. In the American Southwest, astronomer-priests used the Sun to establish calendars for planting, harvesting, and hunting. Obviously, the heavens have always held humankind in their grip, and the attempts to understand celestial mysteries may even have provided the impetus for the first great civilizations.

In the modern age, too, people have been fascinated with the stars.

Since 1610, when Galileo turned the first optical telescope skyward, scientists have sought ways to improve their view of the heavens and to look deeper into space. In this attempt, increasingly larger optical telescopes were created.

Yet, even with the largest optical telescopes, our view is limited by the Earth's atmosphere which filters out all but selected wavelengths of the total radiation from stars. After



CONTENTS

World War II, astronomers using radio telescopes were able to open another window on the universe, in effect, "listening" to the radio wavelengths emitted by celestial objects.

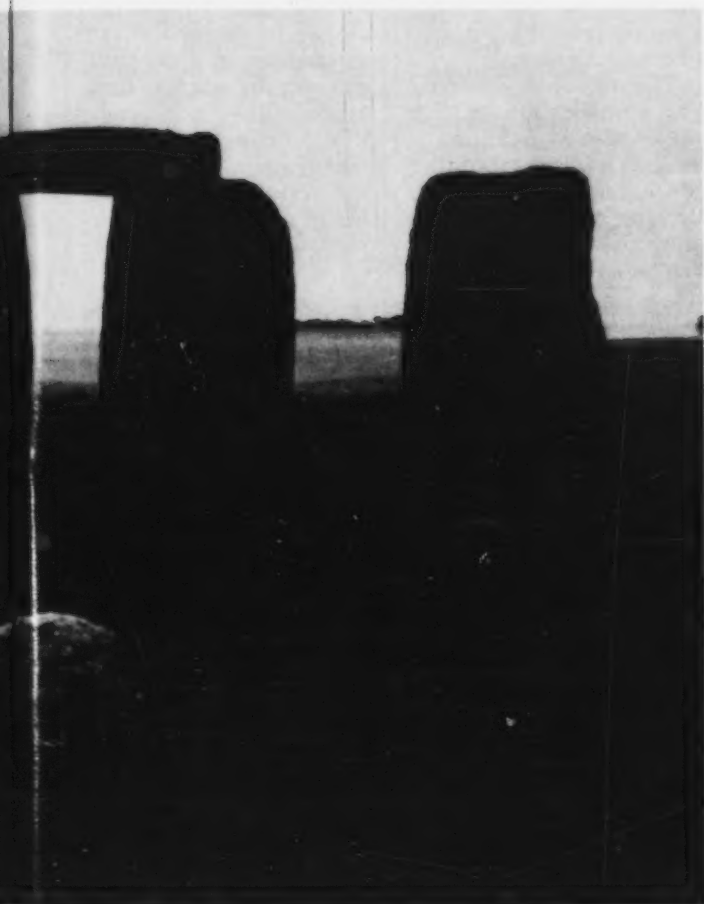
With the advent of the space age, however, astronomers were given an opportunity to carry their instruments above the restricting atmosphere and to observe with special detectors the full spectrum of stellar energy.

Experiments on rockets and telescopes aboard satellites now allow observations of stars in ultraviolet and infrared light, as well as the detection of gamma, cosmic, and X-rays. Indeed, some of the most exciting new discoveries have come from X-ray astronomy. It began almost by accident.

Galileo (At left)

Stonehenge (Below)

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HIGH ENERGY ASTROPHYSICS

In 1962, a group of scientists under the direction of Riccardo Giacconi launched a small rocket carrying instruments designed to detect any X-rays from the Moon produced by energetic solar particles interacting with the lunar surface. No lunar X-rays were seen; but when the instrument scanned the constellation Scorpius it found an intense flux of X-rays. This X-ray source, now known as SCO X-1, has been identified with a faint, irregularly flickering, blue star. The discovery was unexpected, for astronomers thought cosmic X-rays were not detectable.

Even more exciting, SCO X-1 seemed to be a new type of star, in which most of the energy is emitted in X-rays

rather than visible light. Subsequent rocket and balloon flights and orbiting observatories such as the Small Astronomy Satellite (SAS-1), nicknamed "Uhuru", found more than 300 other X-ray sources. Other satellites in the Astronomy series, plus the Ariel (a cooperative venture with Great Britain) and the Netherlands Astronomy Satellite (ANS) found additional sources, plus a strange class of objects that emitted intense bursts of X-ray emission on time scales varying from thousandths of a second to years.

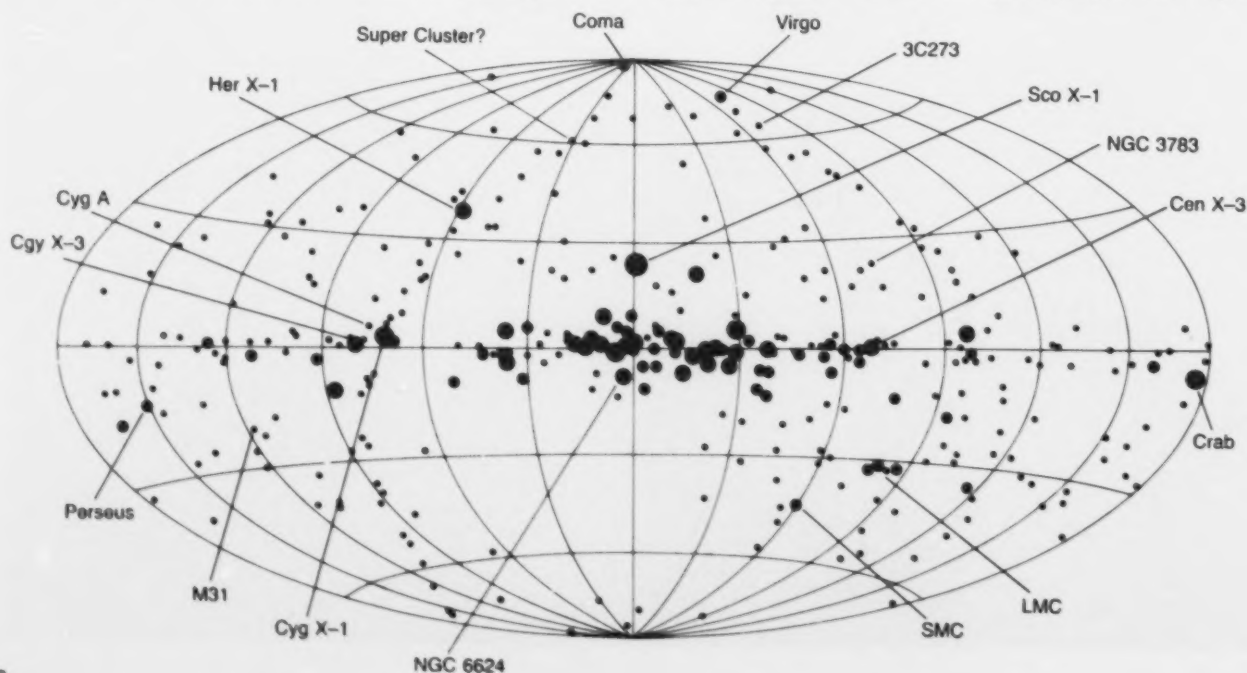
The ability to observe and measure X-rays from space offered astronomers a natural laboratory for testing theories of physics and observing physical processes under

conditions impossible to create on Earth.

The next generation of X-ray, high-energy satellites was designated the High Energy Astronomy Observatories (HEAO) by NASA. The HEAO Series consist of three large scientific satellites built by TRW, Inc. under the direction of the Marshall Space Flight Center. These observatories,

which have complementary missions were launched at about one year intervals beginning in 1977. HEAO 1 was designed to survey the sky for additional X-ray and gamma ray sources and pinpoint their positions. HEAO 2 (the Einstein Observatory) would carry the first telescope capable of producing actual photographs of X-ray ob-

The Fourth Uhuru Catalog map of the X-Ray sky based on observations from The Uhuru satellite.



jects. HEAO 3 would study cosmic ray particles and produce spectroscopic information on gamma rays in space.

In 17 months of operation, HEAO 1 increased the catalog of known X-ray objects to 1,500, discovered a new black hole candidate, found new classes of X-ray stars, and detected active galaxies emitting X-rays. HEAO 3 was launched in September 1979 to open the fields of gamma ray and cosmic ray investigation to intensive study.

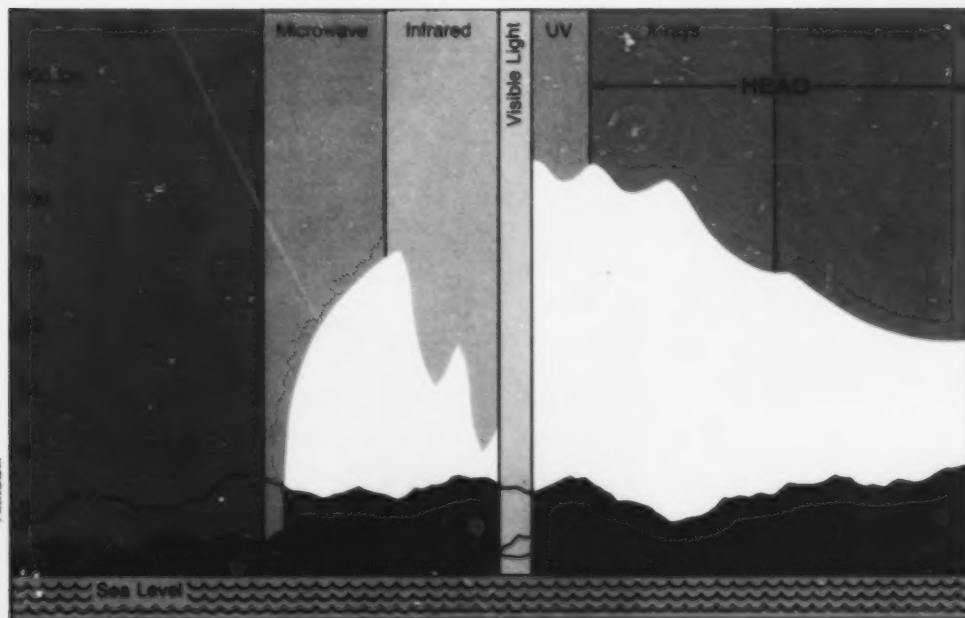
HEAO 2 effectively extended the vision of X-ray astronomers as far into space as they could see with the very best optical and radio telescopes. Almost overnight, the catalog of X-ray objects was more than doubled and

new information vital to understanding the nature of the universe was gathered on supernovae remnants, pulsars, neutron stars, black holes, and cosmic bursters in globular clusters.

HEAO 2's X-ray telescope provided the first images of X-ray sources in galaxies outside our own Milky Way, and discovered the oldest and most distant clusters of galaxies ever seen, the brightest, most powerful, and most distant objects ever seen in X-rays: quasars more than 10 billion light years from Earth. More importantly, the data returned promises to help answer one of the most basic questions in modern astronomy. "Is the universe open or closed?"



Artist's concept of The Uhuru (SAS-1) satellite.



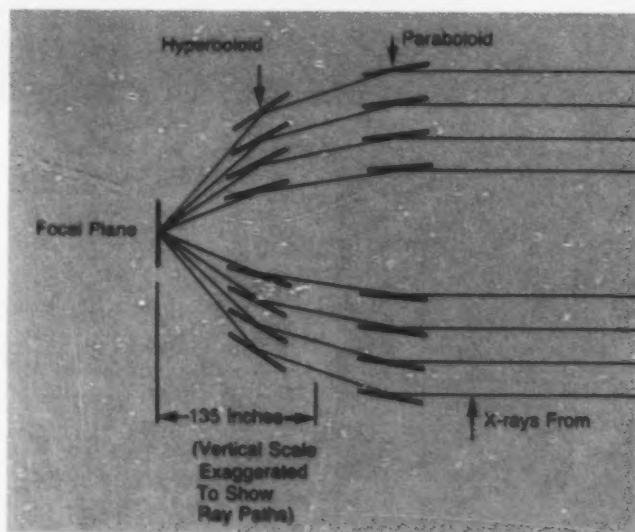
Transparency of the Earth's Atmosphere
Graphic interpretation of the transparency of the Earth's atmosphere to electromagnetic radiation from space.

HEAO 2'S X-RAY TELESCOPE

Shortly after launch, the HEAO 2 satellite was nicknamed the Einstein Observatory by its scientific experimenters in honor of the centennial of the birth of Albert Einstein, whose concepts of relativity and gravitation have influenced much of modern astrophysics, particularly X-ray astronomy.

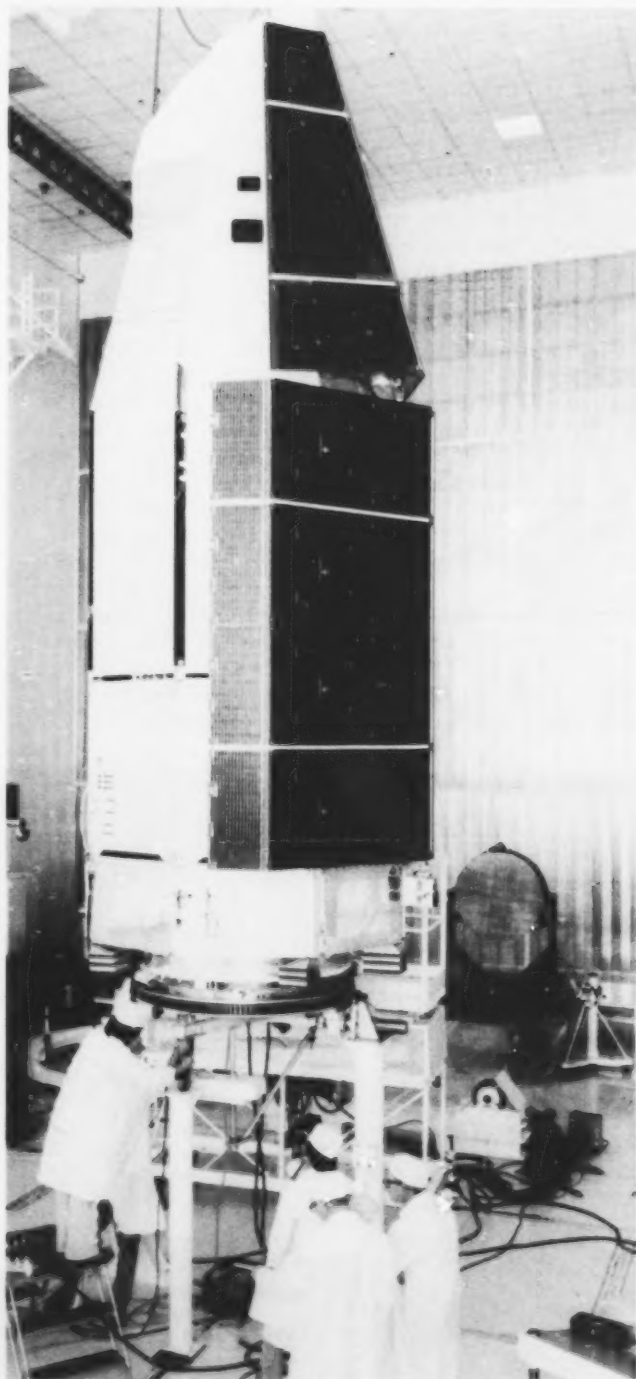
At the heart of this orbiting observatory is a 0.6-meter grazing-incidence telescope sensitive to X-rays rather than visible light. The telescope mirrors are made of a special glass of fused quartz coated with a thin layer of nickel. Unlike

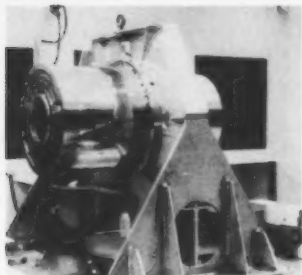
visible light telescopes, the mirrors of the X-ray telescope are not flat dishes but rather are four concentric glass tubes whose inside surfaces are polished to high precision. There is a slight curve in each of the cylinders, so that X-rays strike the mirrors at a grazing angle. Thus, the short wavelength X-rays skip on the surface rather than penetrating the glass. The four concentric mirrors also concentrate the X-rays at a common focus so that objects 1,000 times fainter than ever seen before can be examined in detail. Also unlike previous detectors



The slightly curved surfaces of the mirrors intercept X-rays at a grazing angle and focus them into a single image.

HEAO is prepared for flight





HEAO-2's (HEAO-B's)
X-Ray mirror completely
assembled for ground
testing.

which could merely tell the direction and intensity of an X-ray source, HEAO 2's telescope can form images or pictures showing the shape and arrangement of large, spread-out objects in the sky such as the Crab Nebula.

Four separate astronomical instruments are located at the focus of this unusual telescope and they can be interchanged for different types of observations as the observatory points at interesting areas of the sky. Two of these instruments produce images: a High-Resolution Imaging detector system and an

Imaging Proportional Counter, designed by the Harvard-Smithsonian Center for Astrophysics, Cambridge, Mass. The other two instruments measure the spectra of X-ray objects, that is, their chemical composition. They are the Solid State Spectrometer, designed by Goddard Space Flight Center, Greenbelt, Md. and the Crystal Spectrometer, designed by Massachusetts Institute of Technology, Cambridge Mass.

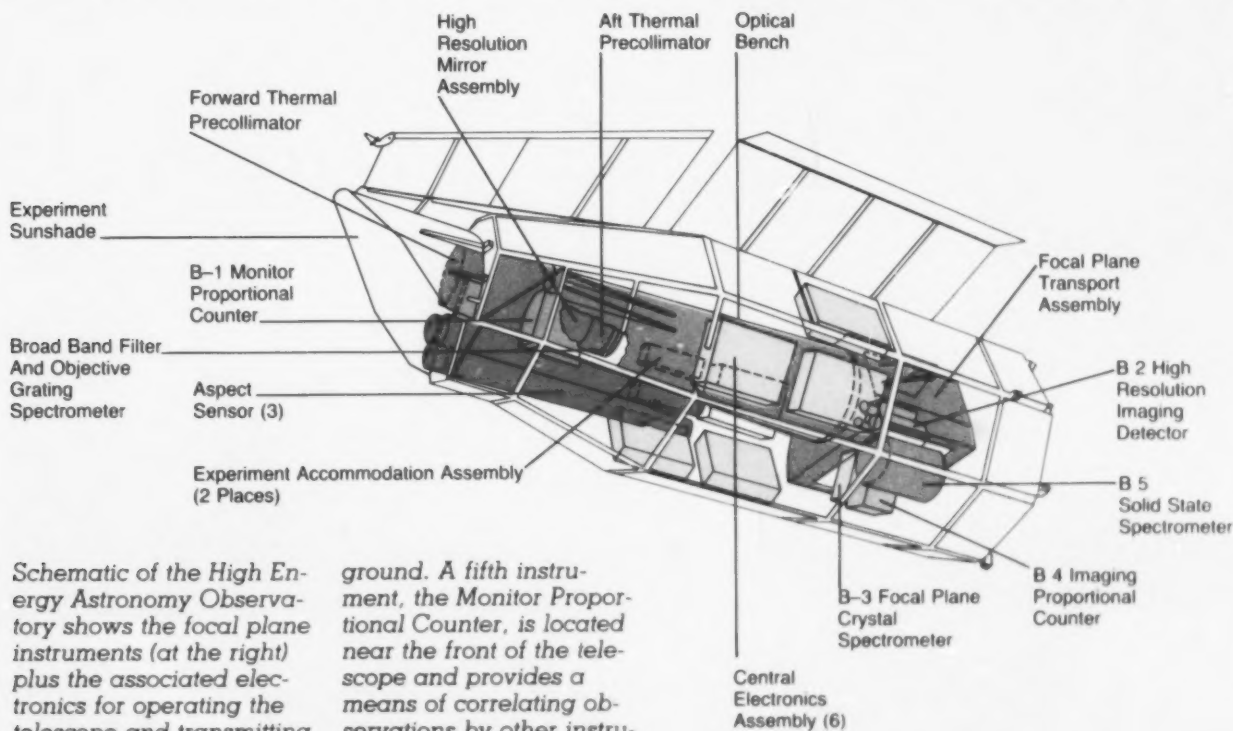
A fifth instrument, the Monitor Proportional Counter, continuously views space independently of the telescope to

study a wider band of X-ray wavelengths and to examine the rapid time variations in the sources.

The observatory is automatically controlled in orbit by a set of rotating precision wheels which provide the desired orientation by minute changes in their rate of rotation. The observatory moves from target to target as commanded from the ground by radio signal. Star trackers provide a reference to the sky based on known positions of the stars. Large solar panels provide the electrical power necessary to operate the instruments and the spacecraft sys-

tems, including the telemetry system that sends the data back to Earth. The scientific data is stored on tape recorders until the observatory passes over a ground station which can receive the data and then forward it to the scientists.

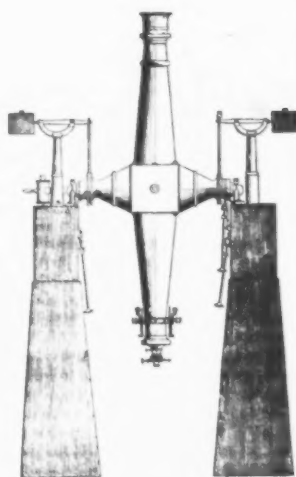
The High Energy Astronomy Observatory program is unique also in that more than 200 guest observers, many of them from outside the United States, use the telescope for scheduled viewing periods. This cooperative aspect makes it a truly international facility, serving the goals of scientists around the world.



Schematic of the High Energy Astronomy Observatory shows the focal plane instruments (at the right) plus the associated electronics for operating the telescope and transmitting its observations to the

ground. A fifth instrument, the Monitor Proportional Counter, is located near the front of the telescope and provides a means of correlating observations by other instruments.

BLACK HOLES



The most popular feature of high energy astrophysics is the black hole, a gravitational anomaly in space that has captured the imagination of the public as well as scientists.

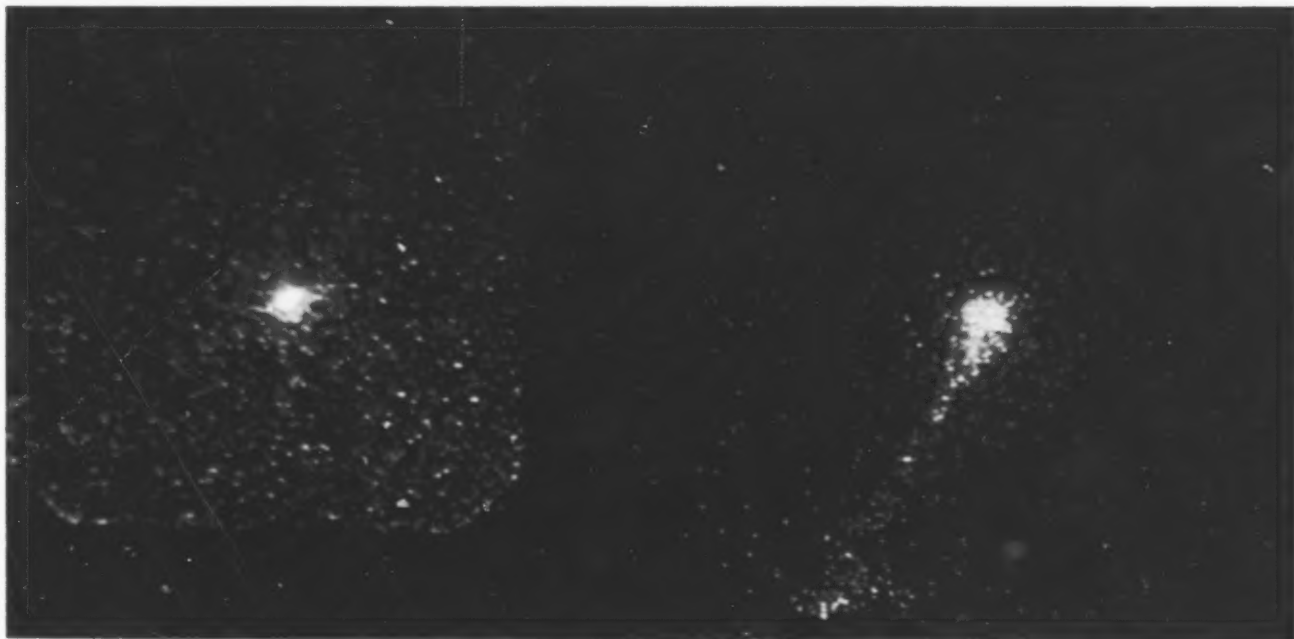
One concept of a black hole, according to current theories, is a star, perhaps ten times more massive than the Sun, which has entered the last stages of stellar evolution. There is an explosion triggered by nuclear reactions after which the star's outer shell of lighter elements and gases is blown away into

space and the heavier elements in the stellar core begin to collapse upon themselves. Once this collapse begins, the inexorable force of gravity continues to compact the material until it becomes so dense it is squeezed into a mere point and nothing can escape from its extreme gravitational field, not even light, hence its name.

However, if the collapsed star is part of a binary system—two stars circling each other like the Earth and Moon—as

tronomers predict that material from the normal star might be sucked into the black hole to produce tremendous flows of high energy radiation, or X-rays. This is what X-ray astronomers suspect they may be seeing in the X-ray emission from several sources.

X-ray astronomers have identified four black hole candidates. The most popular one is Cygnus X-1, a binary system in the constellation Cygnus and one of the first objects at which the HEAO 2's telescope was pointed.



The first object seen by HEAO 2 was the suspected black hole, Cygnus X-1.

*Artist's concept of the
black hole phenomenon
demonstrates the well-like
feature of the gravita-
tional field.*



SUPERNOVAE REMNANTS

On July 4, 1054, Chinese court astronomers reported seeing a "guest star" in the constellation Taurus. It remained brilliant for six months and, for a period of three weeks, could be seen in broad daylight. Nearly 700 years later, the French comet hunter, Charles Messier, reported a fuzzy patch of light in the same area of the sky. Lord Rosse, using the world's largest telescope in 1845, observed this smudge, drew its strange shape, and described it

as looking like a "crab." Today, we know this object as the Crab Nebula, the remains of a giant star that exploded more than 5,000 years ago.

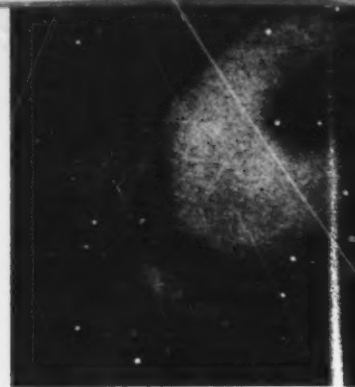
Most stars in the universe are remarkably constant. Occasionally an old, massive star reaches a stage when its nuclear fuel has been nearly depleted and the delicate balance between internal pressure and the gravity holding the star together can no longer be maintained. The star suddenly explodes, spewing

gas and energetic particles millions of miles into space, while its heavier elements collapse into a dense core. For a few days, or even several months, the star—now known as a supernova—shines brilliantly, brighter perhaps than all the other stars in its galaxy combined. It may even be seen in the daylight. Eventually, the glow of the supernova fades. The gas and dust of the star's outer layers continue to expand through space, picking up other interstel-

lar material as they move outward.

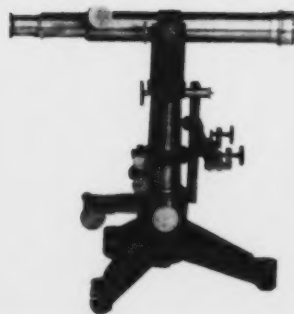
The remnants of a supernova consist of this expanding cosmic debris, a blast wave of energy that expands with it, and the compact remains of the former star at its core. Sometimes this core is detected as a neutron star or pulsar—that is, a rapidly spinning object whose magnetic field is so strong that radiation can escape only along

A view of the Crab Nebula in visible light. The faint object at the center has been identified as a pulsar and is thought to be the remains of the original star, and has been observed as a pulsar in visible light, radio-waves, X-rays, and gamma rays.





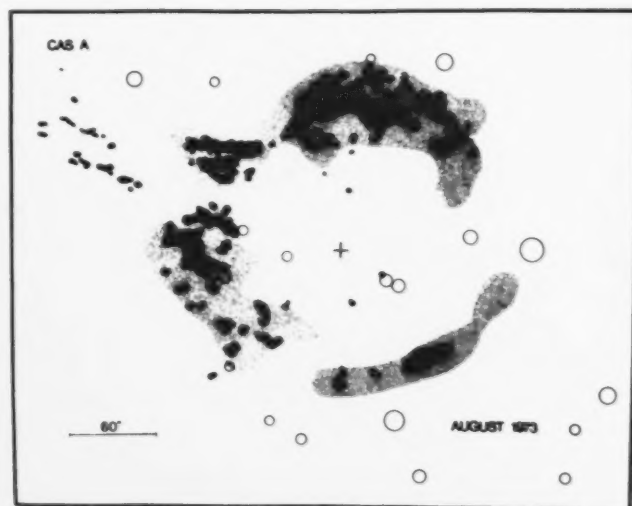
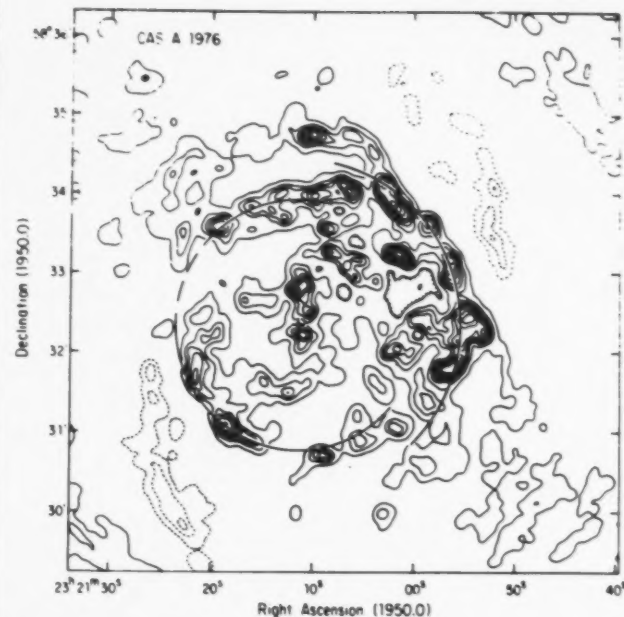
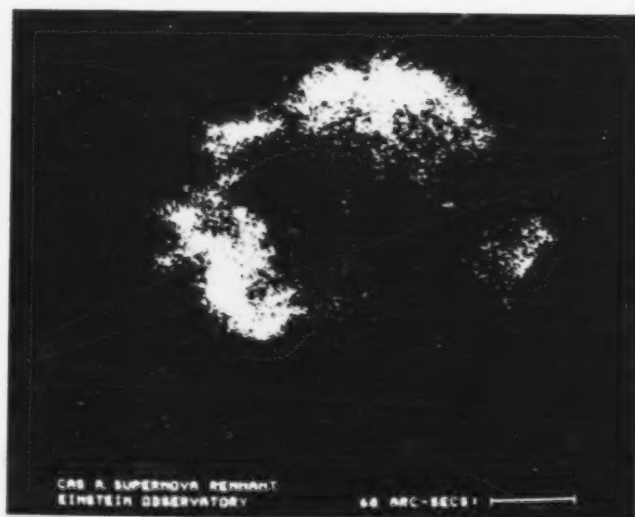
The X-ray image of the Crab Nebula is dominated by the pulsar, which appears as a bright point due to its pulsed X-ray emissions. The strongest region of diffused emission comes from just northwest of the pulsar, which corresponds closely to the region of brightest visible light emission.



the field lines in short bursts like flashes from a cosmic lighthouse.

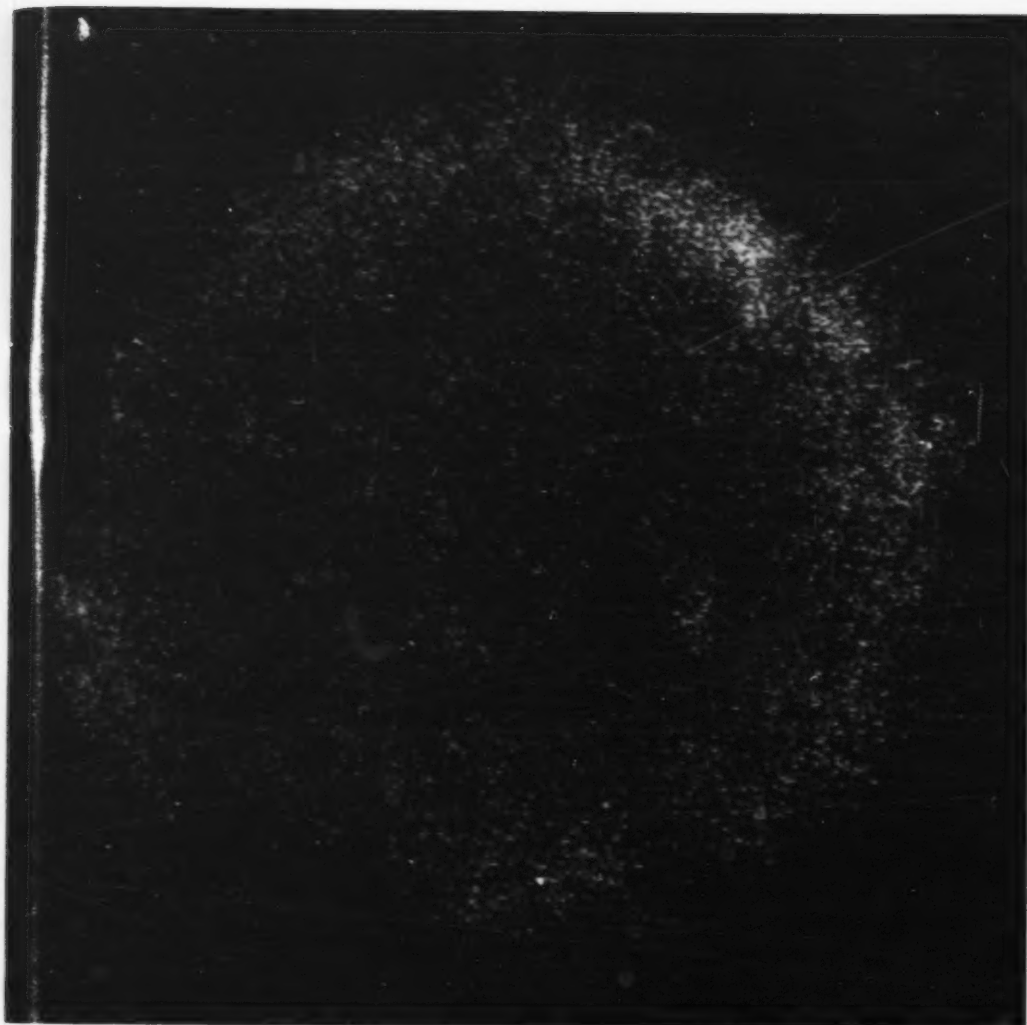
Supernovae remnants are extremely interesting to astronomers. In addition to the pulsars and neutron stars often found at their cores, they may be the source of much other high-energy radiation, and may be the mechanism for dispersing

basic elements through outer space. Some scientists think they may be mini-versions of the "big bang," seeding the universe with the material for new bodies. Indeed, our star, our planet, and even we ourselves must be made up of elements spewed out by an exploding star billions of years ago.

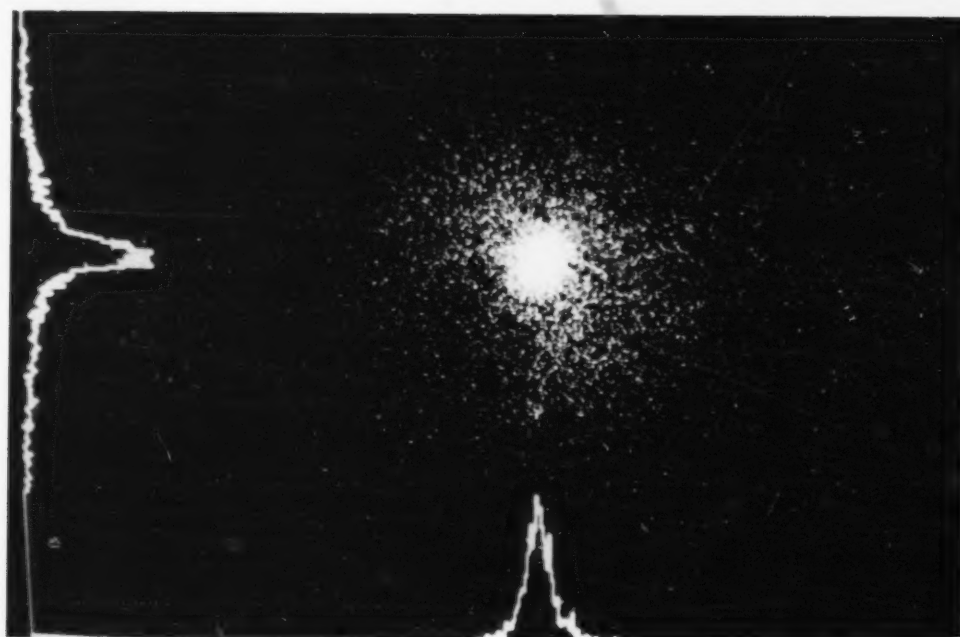


A comparison of X-ray (left) and visible light (right) of the supernova remnant Cassiopeia A shows that those regions with fast-moving knots of material in the expanding shell are bright and clear. A faint X-ray halo just outside the bright shell is interpreted as a shock wave moving ahead of the expanding debris. The radio wave map (top) of Cassiopeia A shows a shell virtually identical with the X-ray picture, but the strongest

areas of X-ray emission are not prominent in radio waves. Oddly enough, each supernova remnant seems to have its own personality. Although some leave behind a visible core star, such as the pulsar in the Crab Nebula, no such object has been found at the center of Cassiopeia A. The evidence of a collapsed star may be an exception rather than a rule. The lack of evidence of a collapsed star in some remnants remains a puzzle.



This supernova in the constellation Cassiopeia was observed by Tycho Brahe in 1572 and its remnant appears as an almost circular shell expanding steadily and evenly. In this X-ray image produced by nearly a day of exposure time, the center region appears filled with emission that can be resolved into patches or knots of material. However, no central pulsar or other collapsed object can be seen.



Like the Crab Nebula, the Vela supernova remnant has a radio pulsar at its center. In this image, the pulsar appears as a point source surrounded by weak and diffused emission of X-rays. This object does not produce X-ray pulses. HEAO 2's computer processing system is able to record and display the total number of X-ray photons on a scale along the margins of the picture. This device allows astronomers to study fine details of brightness variations otherwise lost in the X-ray image.

COSMIC BURSTERS

X-ray observations have clearly demonstrated that something remarkable is occurring at the center of globular clusters. The position of the X-ray burst from Terzan 2 in a visible light picture, was detected within two arc seconds of the cluster's center.

Among the rarest—and most bizarre—phenomena observed by X-ray astronomers are the so-called cosmic bursters.

These sudden bursts of intense X-ray radiation apparently come from compact objects with a diameter smaller than 50 km (30 miles). Yet, despite their miniscule size, a typical X-ray burster releases more X-ray energy in a single brief burst than our Sun does in an entire week.

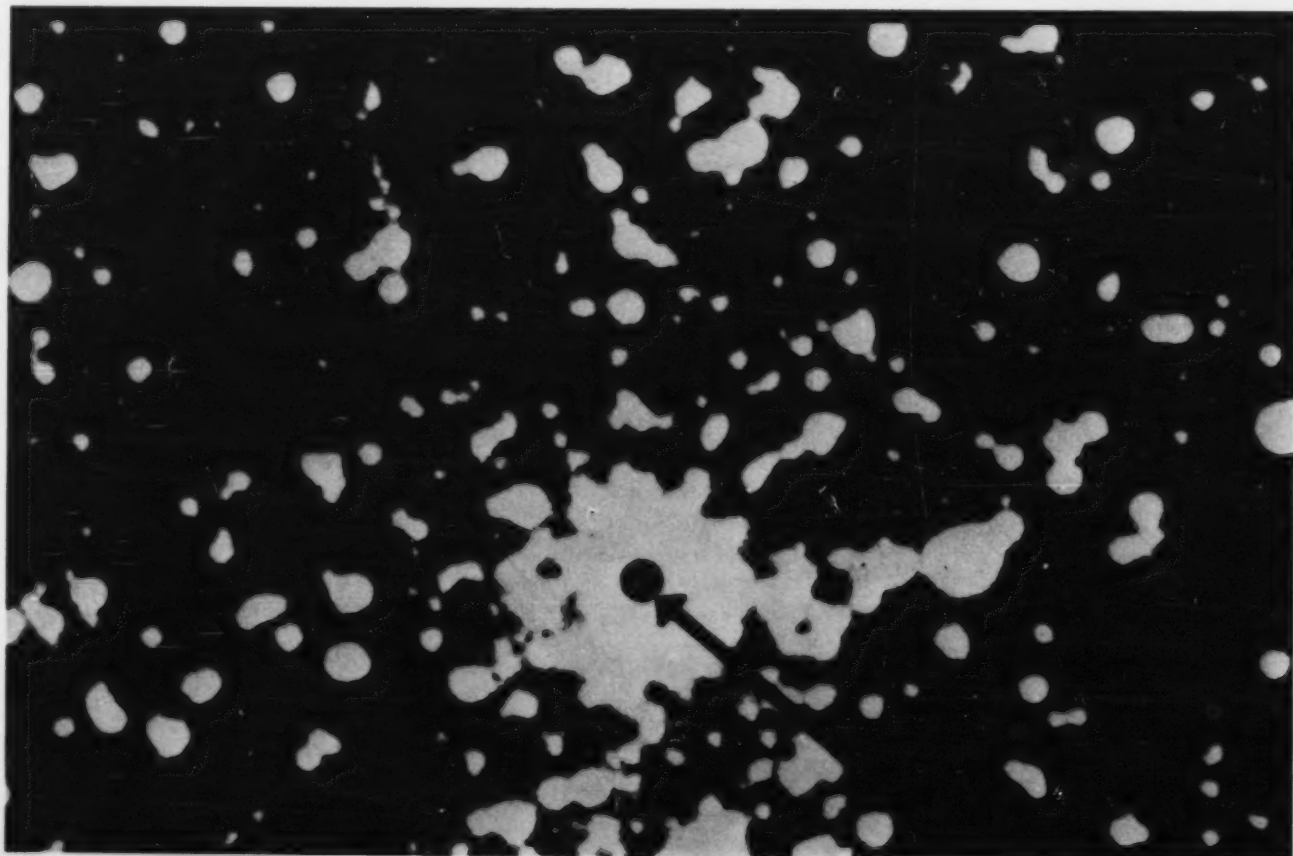
Most of the bursters are associated with globular

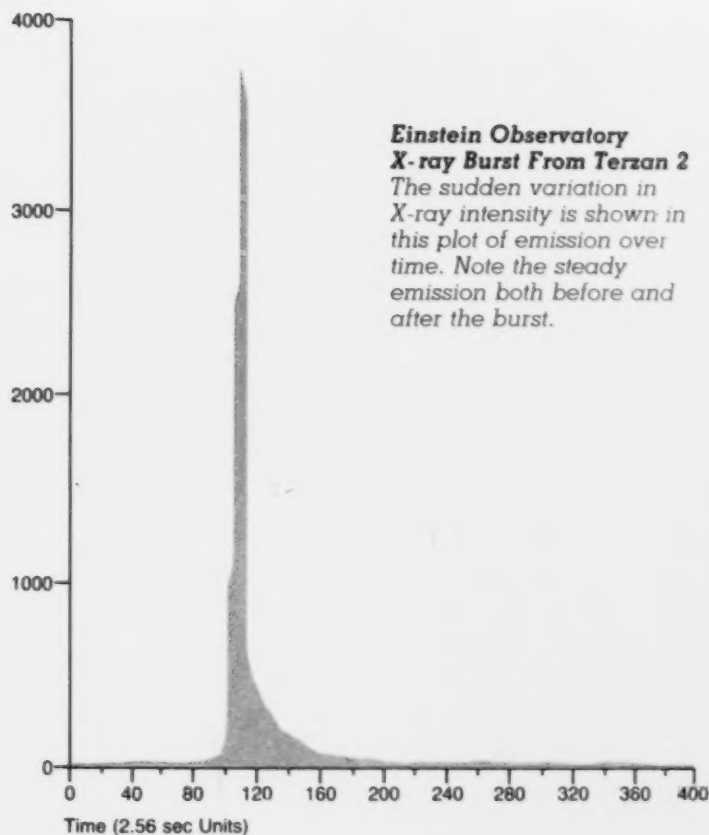
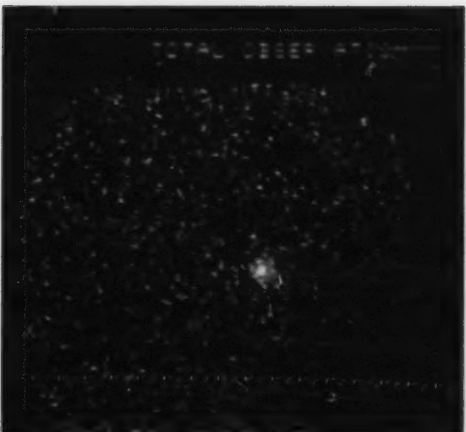
clusters: spectacular, round conglomerations of tens of thousands of stars which are among the oldest objects in our galaxy.

The first X-ray bursters were discovered by a Harvard-Smithsonian Center for Astrophysics experiment aboard the cooperative Netherlands-American satellite in 1976.

Despite several years of observational and theoretical study, the exact nature—and cause—of the X-ray bursts is not

known. They may arise from explosive outbursts of helium on the surface of a neutron star or from violent instabilities in the flow of gas and other material into the gravity well of a black hole. The observations by the High Energy Astronomy Observatory of bursts from the center of globular clusters lend support to the latter hypothesis, suggesting a black hole might be lurking at the cluster's center and literally gobbling up the surrounding stars.





**Einstein Observatory
X-ray Burst From Terzan 2**
The sudden variation in X-ray intensity is shown in this plot of emission over time. Note the steady emission both before and after the burst.

The dramatic change in X-ray emissions from the Terzan 2 cluster is shown in this series of 2.5-minute exposures taken immediately before, during, and after the burst. The total (20-minute) exposure of the object, including the outburst, is shown in the fourth photo. These images represent the first observation of an X-ray burst in progress. The actual burst lasted only 50 seconds.

NEW YOUNG STARS

Today the variable star, Eta Carinae, located in a nebula of the same name, is at 6th magnitude, or about at the limit of brightness one can see with the naked eye. In 1843 this star suddenly flared in brilliance to

equal the brightest stars in the sky. Although now faded in visible light, it remains the brightest object seen in infrared radiation outside of the Sun.

The X-ray observation of the Eta Carinae Nebula proved remarkably



The Eta Carinae Nebula is a large and complex cloud of gas criss-crossed with dark lanes of dust some 6,500 light years from Earth. Buried deep in this cloud are many bright young stars and a very peculiar variable star, Eta Carinae (visible light photograph).



similar to its visible light pictures. Not only could the star (Eta Carinae) be seen and the dark dust lanes in the nebula identified, several other sources of X-ray emission were detected. These points apparently corre-

spond to O stars: hot, young objects still in their early evolutionary stages. Normally these stars are buried so deep in the dust and gas of the nebula that they are seen only by the infrared radiation from the sur-

rounding cocoons of dust. Their detection in X-rays is somewhat surprising. Some hitherto unknown mechanism, perhaps magnetic bubbles in their atmospheres, must be allowing X-ray radiation to escape. The O stars of Eta

Carinae represent an entirely new and unexpected class of objects observable by X-ray astronomers.

X-ray view of Eta Carinae Nebula showing bright O stars.



OTHER GALAXIES

Both of HEAO's imaging devices were used to observe M31. The wide field of view of the Imaging Proportional Counter (A) and the smaller field of the High Resolution Imager (B) are shown superimposed on an optical view of the galaxy.

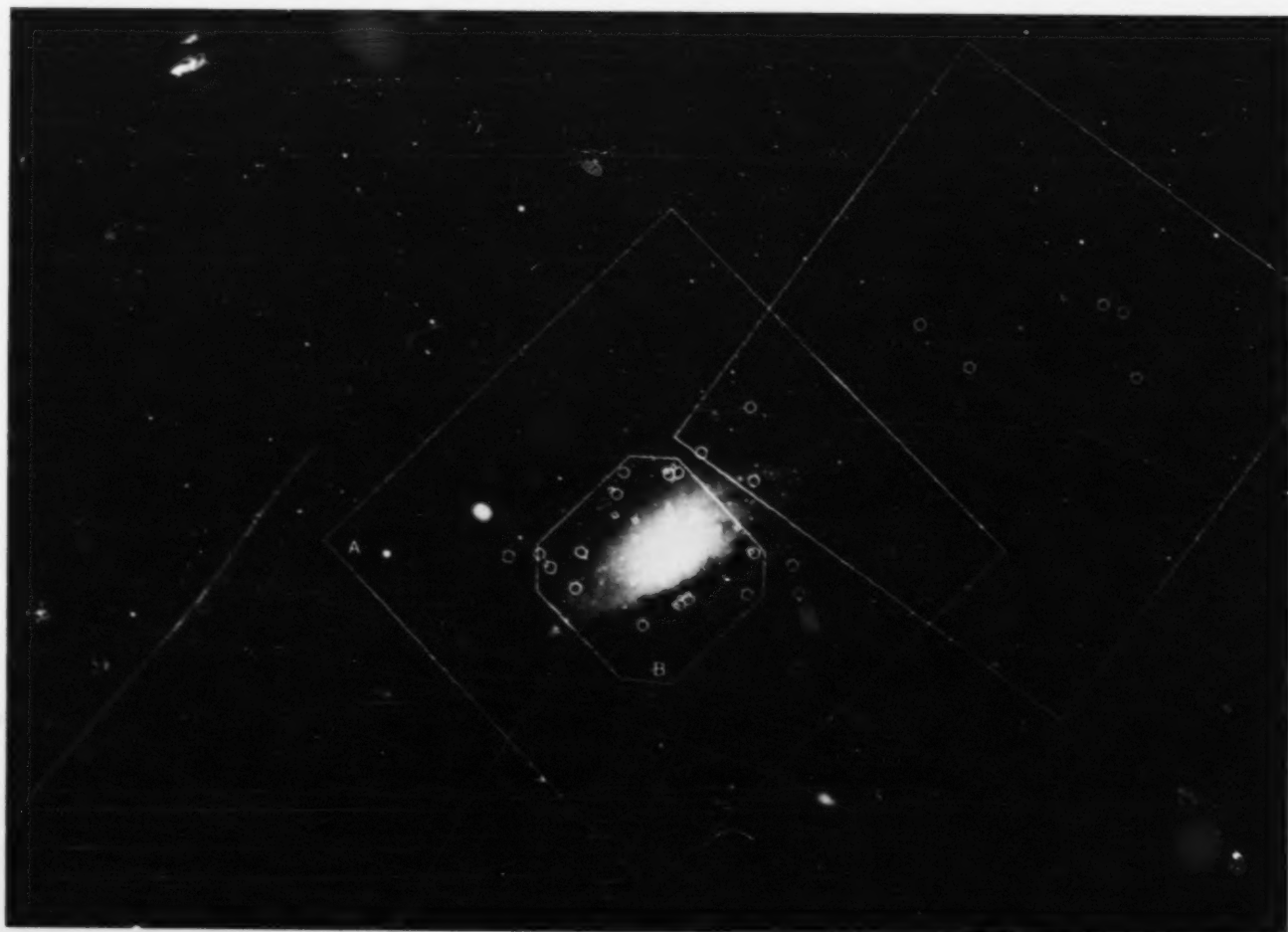
The Great Nebula (M31), located in Andromeda, is both the closest galaxy to Earth similar to the Milky Way and the most distant object visible to the naked eye. It was the first galaxy to be observed with an optical telescope (1612) and the first to be studied by radio telescopes (1939). Previous X-ray experiments had revealed the galaxy to be a general source of X-ray energy, but the second

High Energy Astronomy satellite has the sensitivity and resolution necessary to allow study of individual X-ray objects within the galaxy itself.

HEAO 2 has revealed 72 separate sources of X-rays in this galaxy: 21 sources in the compact inner bulge of the galaxy, 7 globular clusters, 41 objects known as "Population I" sources associated with visible objects as

well as dust and neutral hydrogen, and 8 other somewhat ambiguous sources near the globular clusters.

The nucleus of M31 seems related to a very strong X-ray source, unlike the center of our own galaxy from which no X-ray emission has yet been detected. In fact, almost a third of all the X-rays emitted by M31 seem to come from its central region.





*A wide field X-ray view
(A) of the center region of
the Great Nebula in
Andromeda.*



*A more detailed view (B)
of the M31 center taken
with the High Resolution
Imager.*

CENTAURUS A



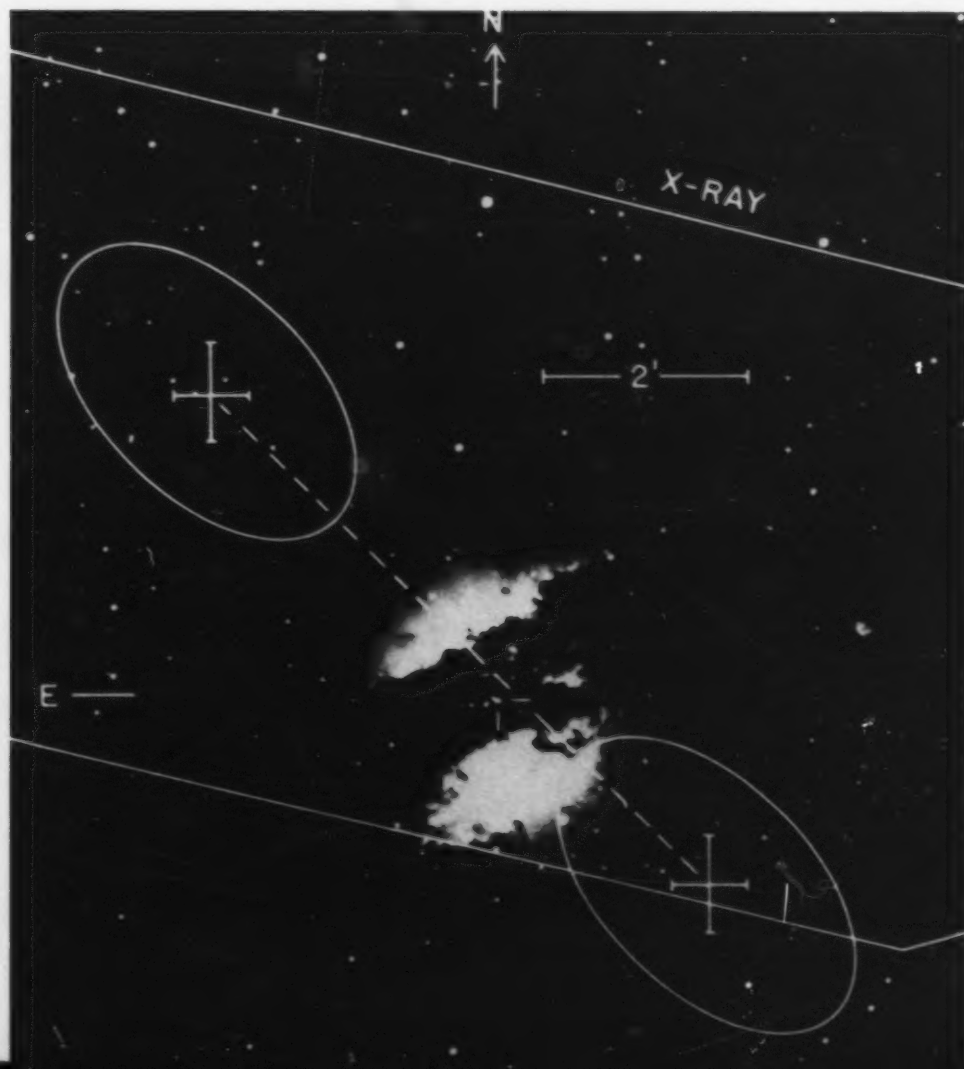
Using radio techniques, astronomers identified a double source of radio wave emission associated with the active galaxy NGC 5128 in the constellation Centaurus. Observations by the first X-ray observatory, the Small Astronomy Satellite, also found that this area, known as Centaurus A, was a strong source of X-ray emissions. Later X-ray obser-

vations showed most of the emission came from the nucleus of the galaxy, with much smaller amounts from the areas which emit radio waves.

HEAO 2's imaging detectors have now resolved the X-ray source at the center of the galaxy into several distinct components: a point source associated with the nucleus, an extended region of X-rays around the nu-

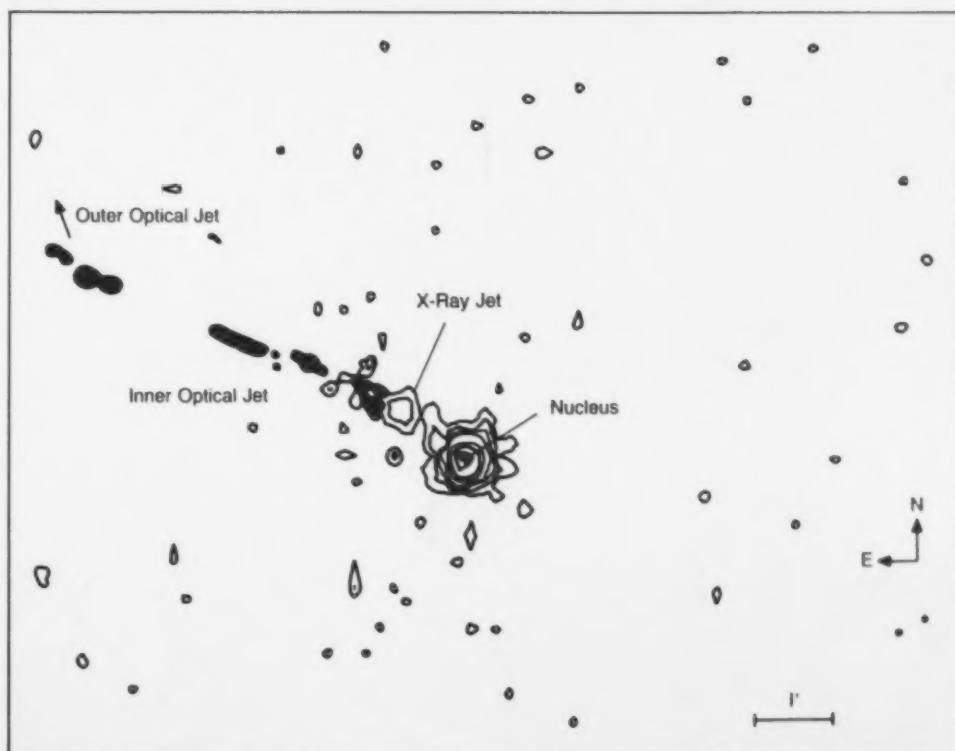
cleus, a diffuse emission region coincident with the two nearby radio wave emitting areas, and an X-ray jet between the nucleus and one of the radio regions.

The double radio signal and the broad area of X-ray emission seen by the Small Astronomy Satellite from Centaurus A are superimposed on this visible light view.





(top) Photo of X-ray sources in Centaurus A. (Bottom) Map of Centaurus A. The extended region about the nucleus may be due to emission from a cloud of hot gas, cosmic scattering, or stellar sources. The jet suggests the radio regions are constantly resupplied with energy from the nucleus.



CLUSTERS OF GALAXIES

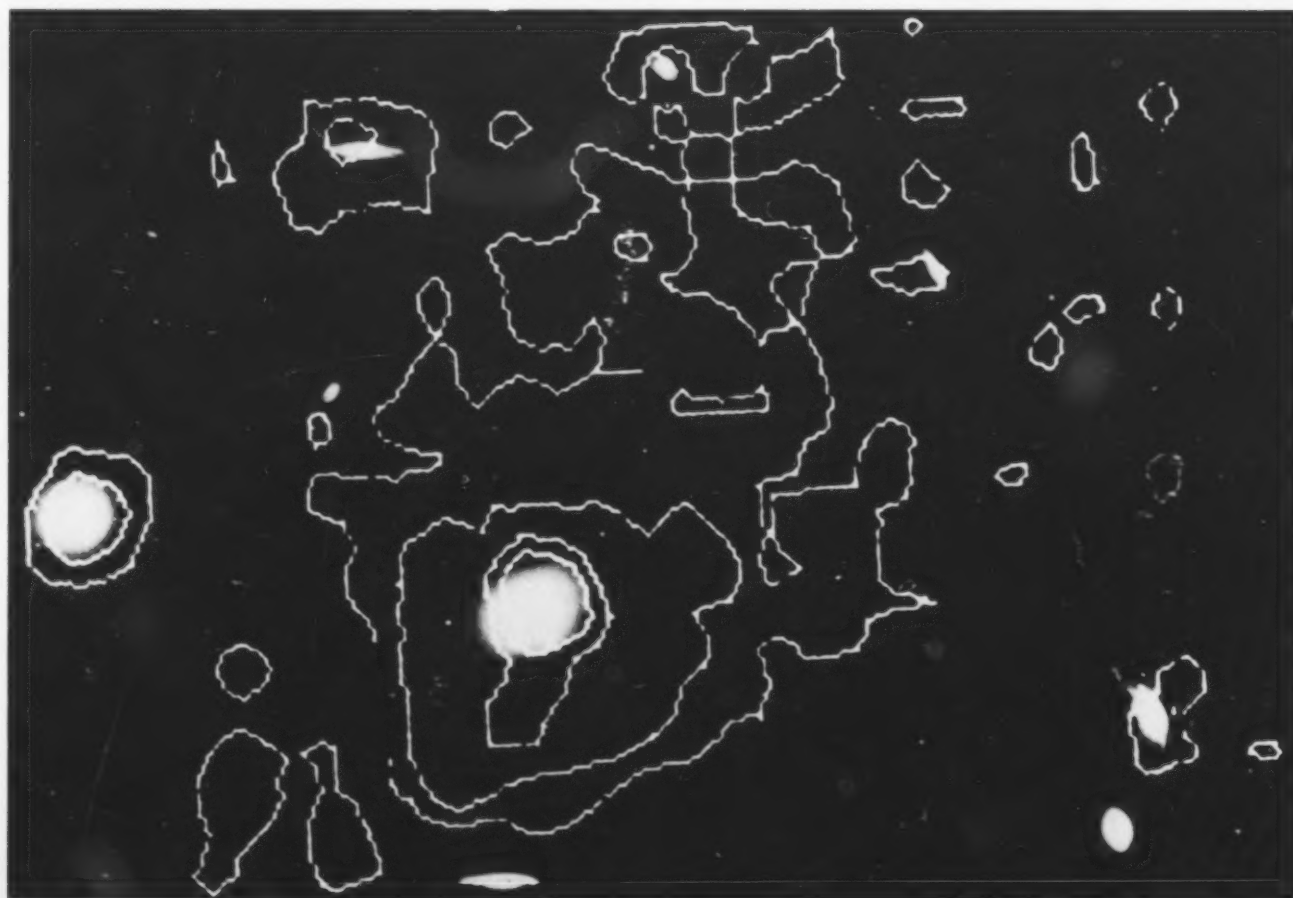
Although the stars seem uniformly distributed across the night sky, in fact, material in the universe is clumped together in great, uneven masses. Our own Sun, for example, is but one of a billion others bound by gravity to the Milky Way galaxy. Billions of other galaxies are scattered throughout space, and many in turn are grouped in great clusters and superclusters each containing anywhere from a half dozen to several hundred galaxies. The Milky Way gal-

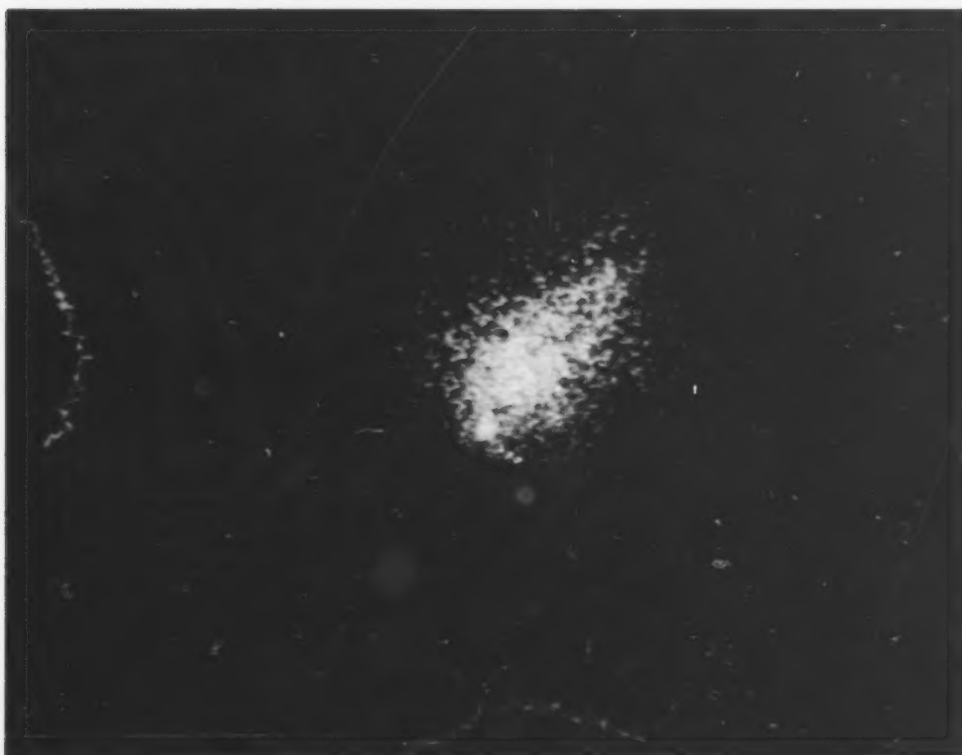
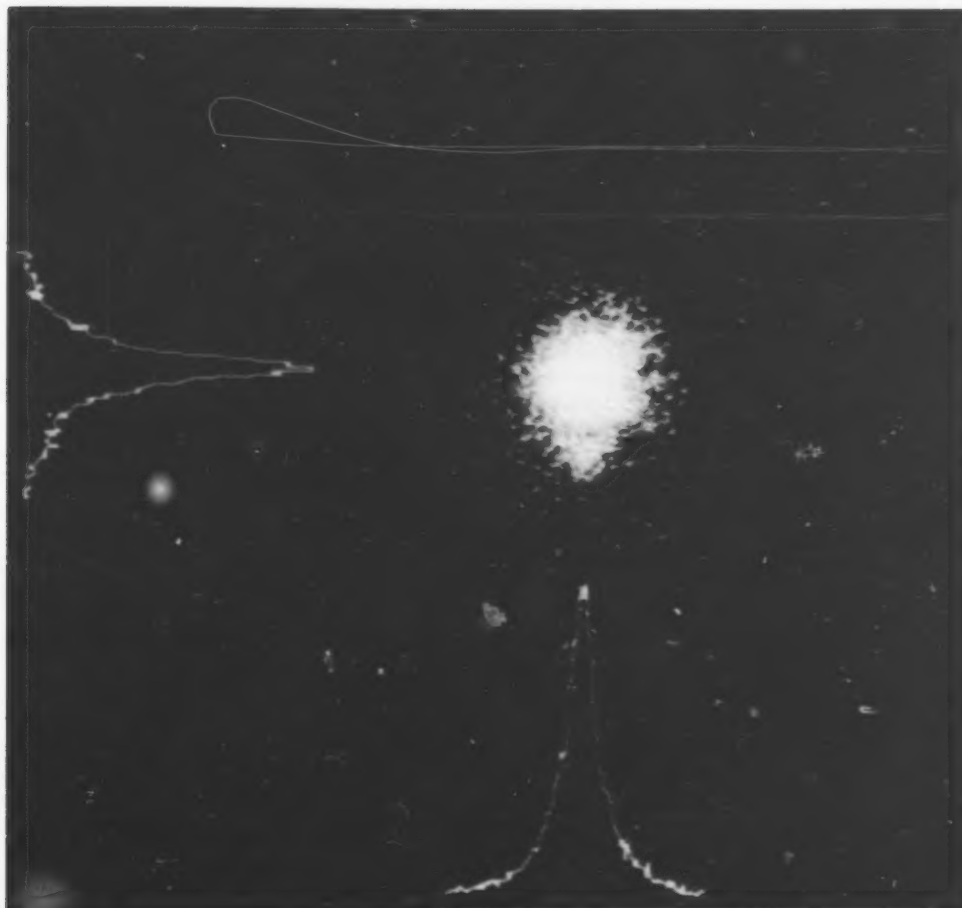
axy is actually part of the Virgo supercluster.

Several clusters were discovered to emit X-rays by both the Small Astronomy Satellite and the British X-ray satellite. More recently, instruments on the first High Energy Astronomy Observatory HEAO 1, found those clusters containing a supergiant elliptical galaxy had most of their X-ray emission associated with that galaxy. The second observatory has observed X-rays from clusters at distances com-

parable to the deepest views in visible light wavelengths. In addition to charting these massive conglomerations—the largest aggregates of matter known to exist—the observations are helping to reveal the history of their formation. It is still not known if the clusters formed directly from vast dust clouds at an early stage of the universe or if later, after the galaxies themselves formed, they were somehow bound together by gravitational processes.

The X-ray contours of the Virgo cluster are superimposed on a visible light photo of four galaxies in the same field.





The X-ray pictures of distant clusters range from the broad and highly clumped emissions of galaxies such as A 1367 (bottom) to the smooth and centrally peaked emissions of A 85 (top). The first type, thought to be in an early stage of evolution, tends to be rich in spiral galaxies and low in both X-ray temperatures and velocity dispersions. The second type is older, with few spirals, higher temperatures and higher dispersions.

DEEP SURVEY

A deep survey photo shows several previously unresolved X-ray objects. (At right) The same objects are identified in a visible light view. (Below)

The first rocket carrying an X-ray instrument into space made one surprising discovery that has intrigued and puzzled astronomers ever since. Not only did it see distinct objects that emitted X-rays, it detected a low level of X-ray radiation from all parts of the universe. Although some of the radiation came from our own galaxy, most seemed to come from



deep space far beyond the Milky Way.

What caused this pervasive X-ray glow throughout the entire sky? Was it a hot, invisible gas distributed evenly among the stars? Or was it simply radiation coming from countless sources, such as galaxies, quasars, and galactic clusters, so far away they could not be seen with the early X-ray de-

tectors?

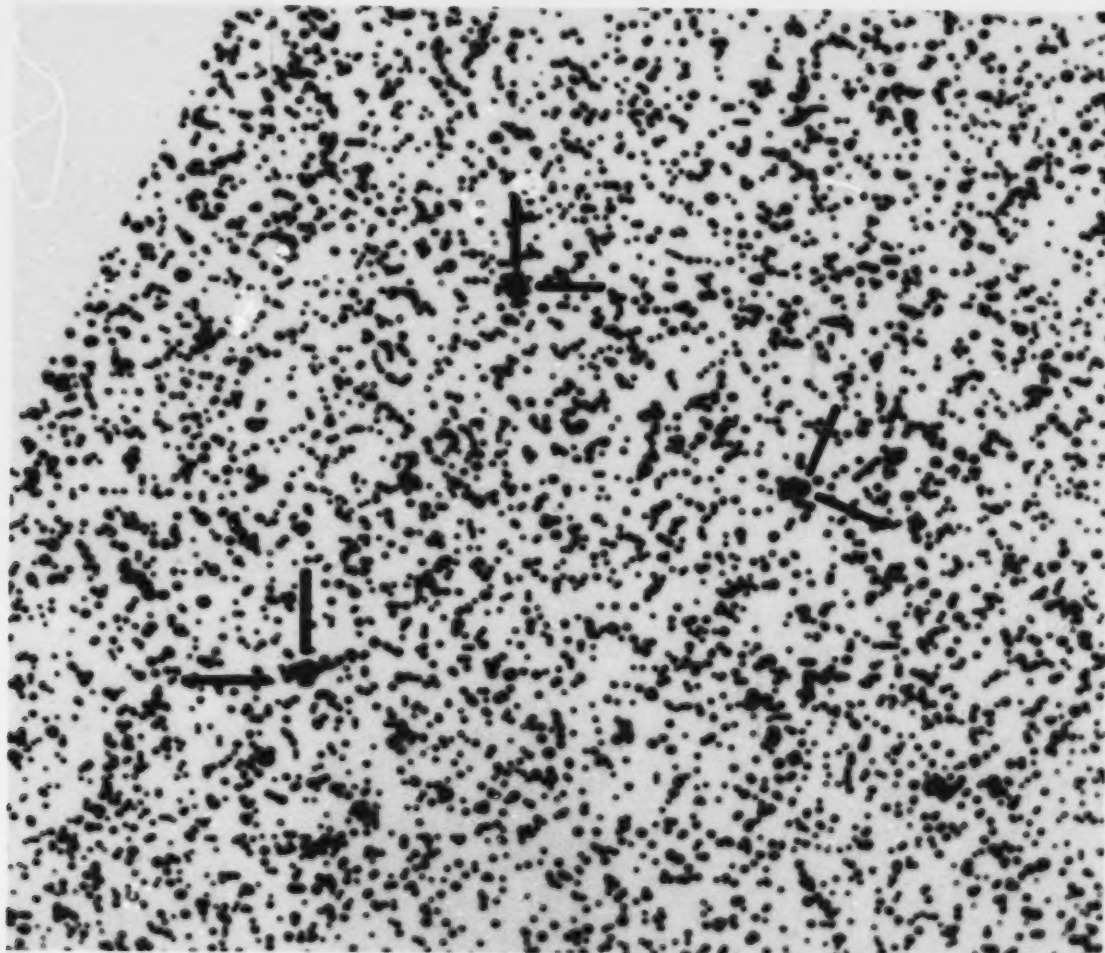
Fortunately, the X-ray telescope aboard HEAO 2 has a 100 to 1,000 times greater sensitivity than other detectors and thus can resolve previously unseen objects and allow their comparison with visible light and radio wave pictures of the same objects.

To study the nature of this extragalactic X-ray background in the uni-

verse, regions of the sky were selected which contain little of the hydrogen gas which absorbs X-rays and no known X-ray emitters or in fact any objects which could be seen or detected by radio waves. In other words, the astronomers wanted to look at a dark, unspectacular part of the sky to see if anything unusual could be observed.

In two such surveys,

HEAO 2's X-ray telescope found 43 X-ray objects. Subsequent surveys revealed a sky studded throughout with scores of X-ray sources. These results suggest that the so-called all-sky X-ray background is actually produced by radiation from vast numbers of previously unseen sources. This discovery has important implications for theories of cosmic evolution.



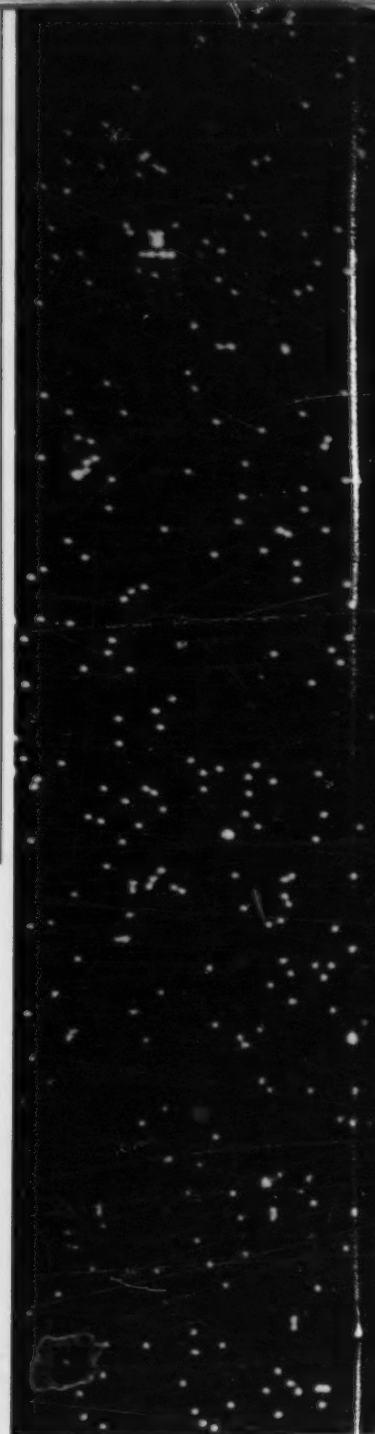
QUASARS

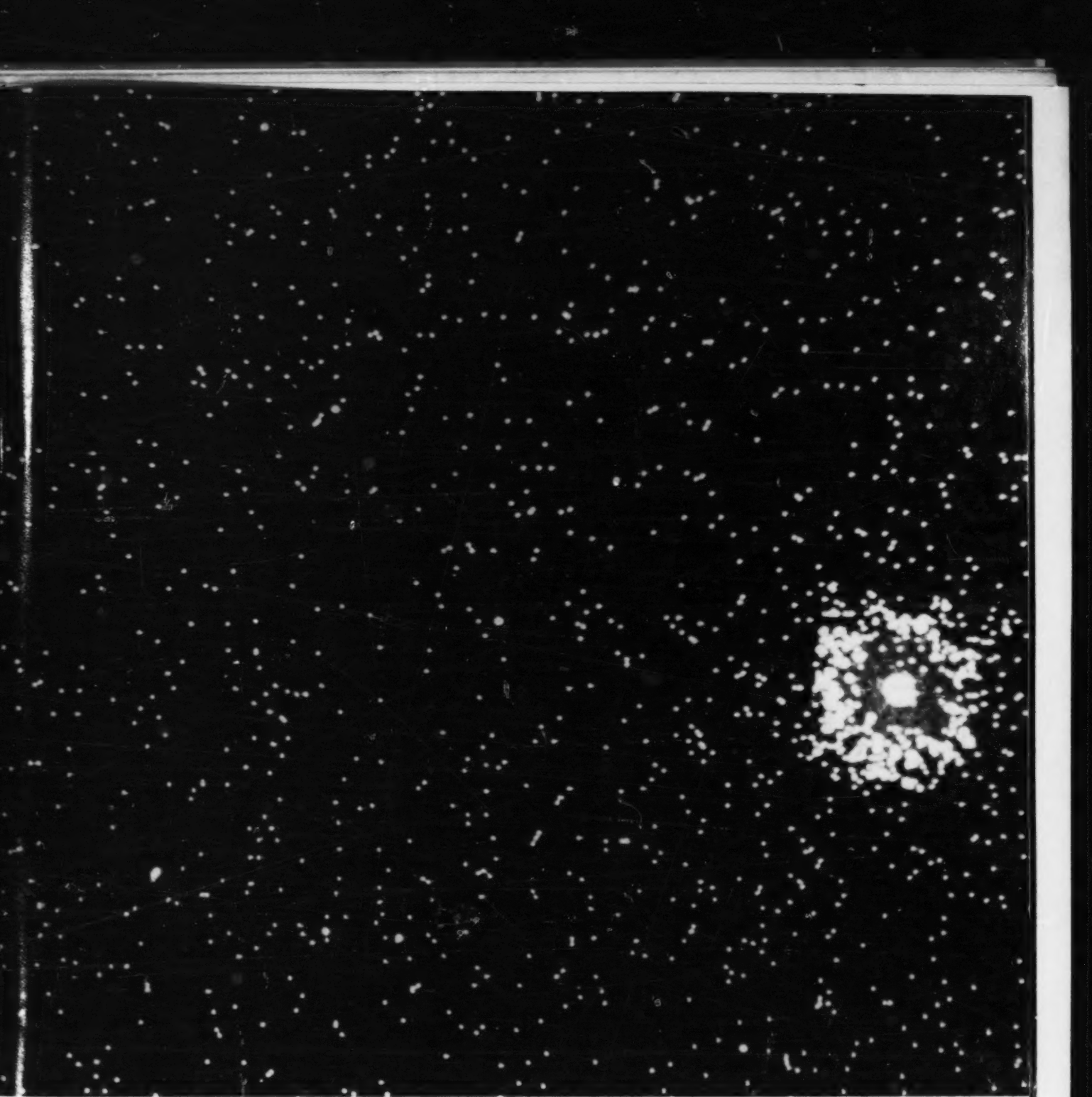
Quasars are mysterious, bright, star-like objects apparently located at the very edge of the visible universe. Although no bigger than our solar system, they radiate as much visible light as a thousand galaxies. The quasars also emit radio signals and have been found to emit X-rays as well. The X-ray telescope has also discovered several bright points in otherwise featureless sections of the sky.

When checked against visible light views of the same field, these objects were revealed to be quasars 10 billion light years from Earth—the brightest, most distant, and most powerful objects yet observed to emit X-rays. The intense emission from these objects and their unusual number, about 150 so far, suggests that quasars may contribute significantly to the widespread X-ray background seen throughout the sky.



The Quasar 3C 47 as seen in X-ray wavelength. The other image on the left is a "normal" star also emitting X-rays.





HEAO 2 observations of Quasar 3C 273, previously recognized as an X-ray source, revealed the presence of a new source (upper left) with a red shift which indicates that it is about 10 billion light years away. The most distant quasar detected by visible light means is estimated to be 15.5 billion light years away.

OTHER RESULTS

The astrophysical plasmas studied with HEAO 2 are characterized by temperatures of 10 million degrees. At these temperatures, which are more than a thousand times that of the photosphere of the Sun, the light elements are completely ionized and hence are invisible. X-ray spectra and, in particular, emission lines from heavier elements which may be major constituents of these spectra, then become a unique means of probing the temperatures, density, magnetic fields, and elemental abundances of the most powerful sources of energy in the sky.

Thus, the second High Energy Astronomy Observatory also carries two instruments for studying X-ray spectra. The Crystal Spectrometer is comparable to an optical prism in that the wavelengths (colors) of X-ray light are separated and studied individually. The Solid State Spectrometer is capable of measuring the entire spectrum at once. The two spectrometers complement each other in sensitivity and energy resolution.

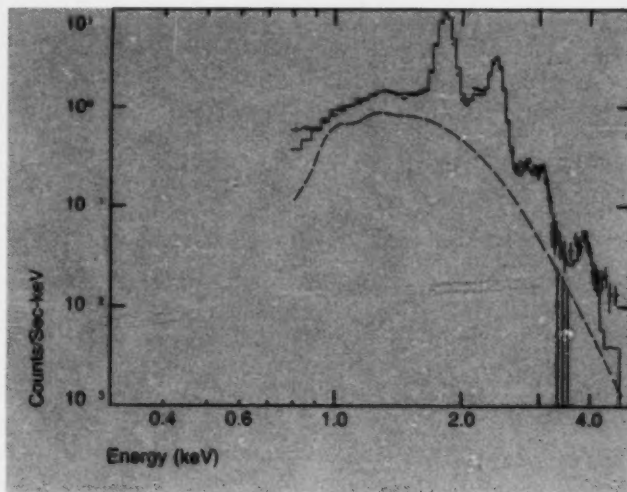
Before HEAO 2, only silicon and iron line emission had been identified in X-ray spectra. Now, in the spectra of at least a half a dozen supernova remnants, thermal emission lines arising from highly ionized states of magnesium, sulphur, argon, and calcium

in addition to silicon and iron have been detected. Since heavy element synthesis occurs only in the latest stages of stellar evolution which culminate in supernovae, the emission seen is from freshly synthesized material.

The abundances measured, correlate with solar system abundances giving confirmation that the Sun and planets were formed out of the debris of similar supernovae which exploded billions of years ago.

HEAO 2 has discovered X-ray emission lines, arising from high temperature plasmas or the fluorescence from cooler material irradiated by X-rays. Emission lines also come from a host of other exotic astrophysical systems ranging from hot stars, through binary systems containing white dwarfs, neutron stars or black holes, to the gas which permeates clusters of galaxies.

The implications of these new measurements on the theories for explaining such systems are only just emerging. Also, the demonstrable sensitivity to X-ray line emission makes the failures to detect line features from other sources particularly significant. Quasars and Seyfert galaxies, for example, appear to totally lack significant emission features, as would be expected if the X-rays were non-thermal in origin.



Tycho X-ray Spectrum-HEAO 2 Solid State Spectrometer-Two-Temperature Collisional Equilibrium Model. This is a High Energy Astronomy

Observatory spectrum of Tycho's supernova remnant. The peaks in the top curve represent isotopes of silicon as well as some other elements.

THE UNIVERSE: OPEN OR CLOSED?

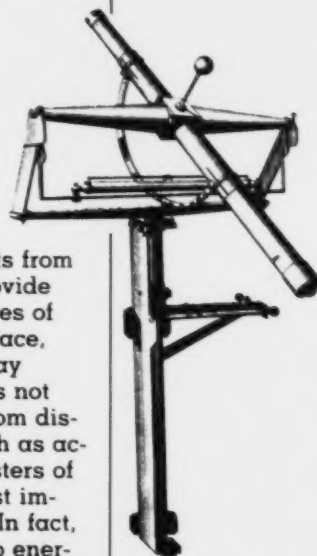
Astronomers now believe that the universe began with a giant explosion some 10 to 20 billion years ago. The energy and the material generated by this explosion have been rushing outward ever since. Some of this material has coalesced into clumps including galaxies, stars, and planets, but all are still rushing outward, propelled by the force of that initial "big bang."

Will this expansion ever end? Will the material eventually reach the point where it can expand no farther and will the force of gravity bring it back together again to repeat the cycle of cosmic birth and death?

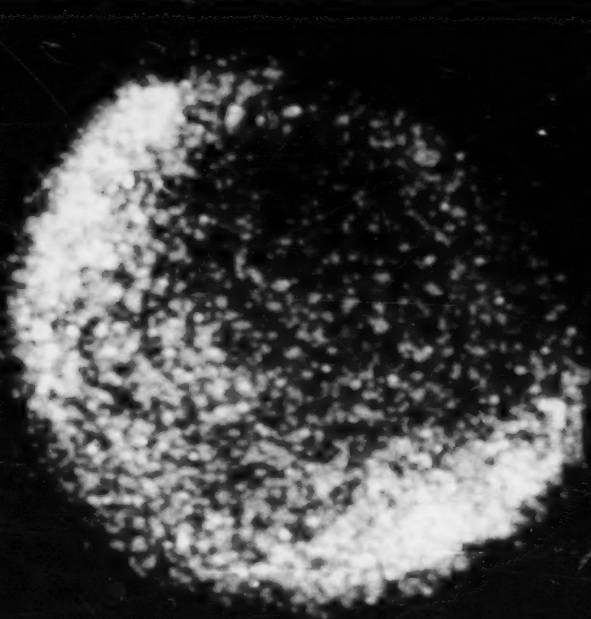
The evolution—and ultimate fate—of the universe is one of the most

basic questions pursued by astrophysicists. Central to the solution is an accurate determination of the amount of mass in the universe. If enough material—stars, planets, gas, and dust—exists, then eventually gravity would act as a brake to halt the outward rush. However, using radio and visible light techniques astronomers cannot find sufficient mass among the visible objects in the sky. At first, the discovery of the diffuse X-ray background suggested that the "missing mass" might be present in the form of an extremely hot gas spread throughout the universe but invisible to normal telescopes. Indeed, observations by HEAO 1 seemed to indicate this gas did exist.

Now, new results from HEAO 2 which provide the clearest pictures of objects in deep space, imply that the X-ray background comes not from a gas, but from discrete sources, such as active galaxies, clusters of galaxies, and most important, quasars. In fact, the quasars are so energetic and so bright in X-rays, that astronomers feel they must contribute a significant fraction of this background level. But, although they are numerous, the aggregate mass of all the quasars still would not be enough to provide the gravitational force needed to halt expansion. The universe, accordingly, is believed to be open and therefore, destined to expand forever.



In the year 1006, a very bright supernova was seen in the constellation Lupus. Although nearly invisible today, it has a bright X-ray image of the same apparent size as the full Moon. It does not seem to contain a central pulsar.



HEAO 1

The first High Energy Astronomy Observatory (HEAO 1) launched in 1977 did an all-sky survey, mapping X-ray sources throughout the celestial sphere. It also measured and mapped low-energy gamma rays and their sources. The initial survey was completed in six months, the satellite's design lifetime, and it continued to scan the skies for a total of 17 months until its control gas was exhausted in January 1979. This first observatory reentered the Earth's atmosphere and was destroyed on March 14, 1979, the 100th anniversary of Albert Einstein's birth.

During that period, HEAO 1 increased the number of known celestial X-ray sources from 350 to 1,500. It discovered a new black hole candidate and indicated the possible existence of a universal hot plasma which would constitute a major fraction of the mass in the universe.

Another discovery was that of a superhot, super-

bubble of gas with a mass equal to 10,000 suns, enveloping a cluster of hot young stars. The bubble is relatively close—6,000 light years away—and is 1,200 light years in diameter. (A light year is the distance light travels in a year, or about 5.8 trillion miles.) Investigators believe the superbubble was formed by a succession of 30 to 100 supernovae (exploding stars) three to five million years ago. The material from these initial supernovae, dispersed into space, caused perhaps 1,000 new stars to form. Some of these were of the type that within a million years, burn up their fuel, collapse, and explode into more supernovae. If the theory is correct, these chains of star formation may be a major mechanism for making new stars. The Sun may well have been formed at the edge of a similar bubble. There may be 200 or more such superbubbles scattered throughout our galaxy, the Milky Way.

HEAO 3

The third observatory, HEAO 3, weighing 2,948 kilograms (6,500 pounds) at liftoff, carried three scientific experiments—a gamma ray spectrometer, a cosmic ray isotope experiment and a heavy cosmic ray nuclei experiment.

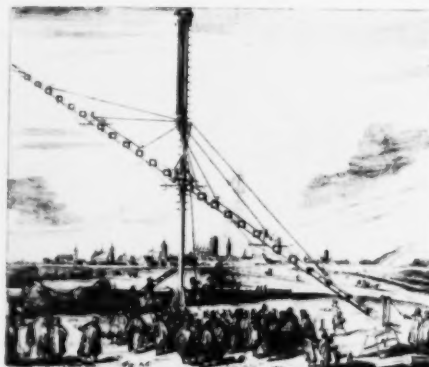
The mission differed from the previous two in the series in that HEAO 3 was looking at the universe through different eyes. The two previous spacecraft conducted X-ray surveys and looked at particular X-ray sources. This observatory was designed to scan the heavens primarily for cosmic ray particles and gamma ray photons.

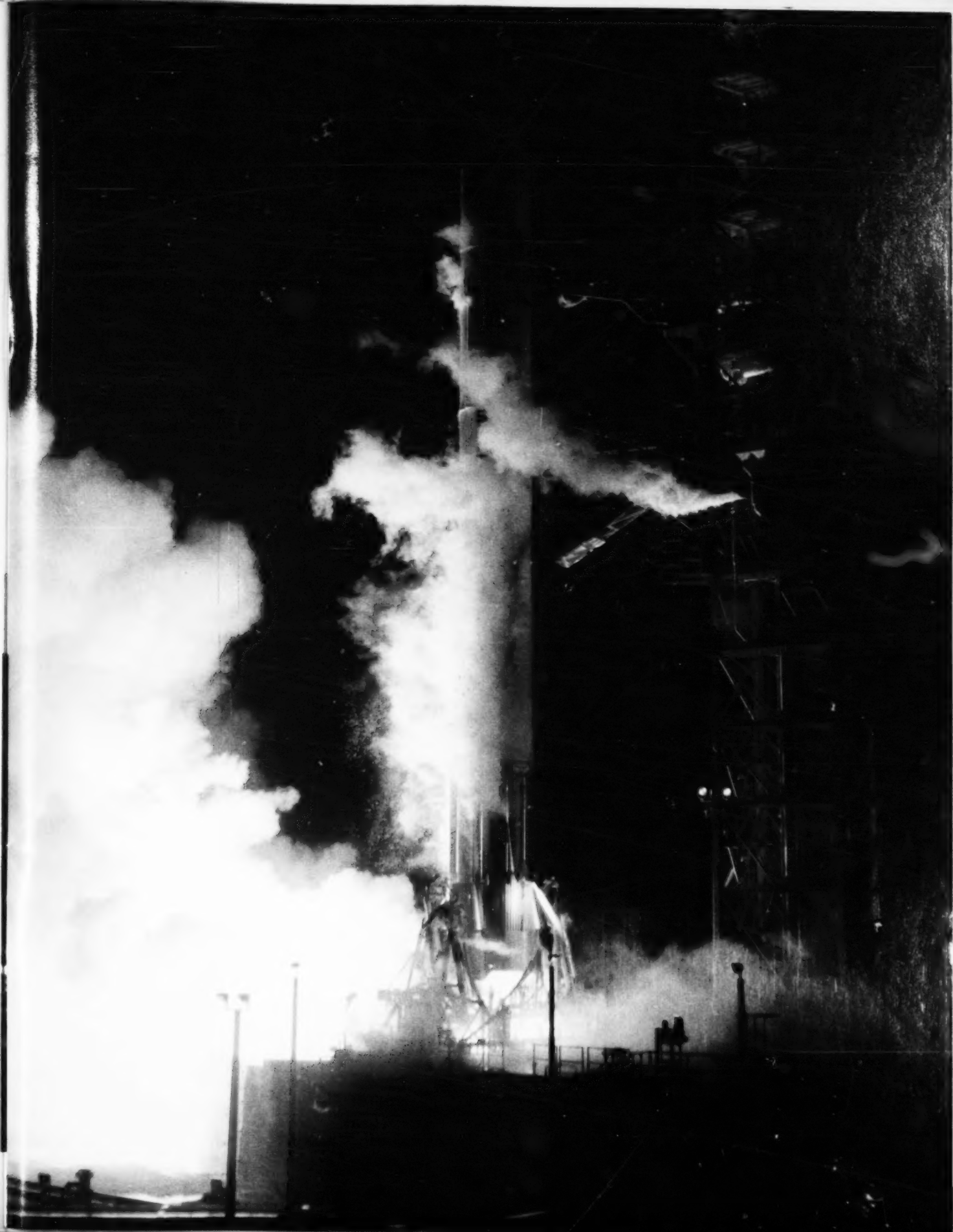
Cosmic rays are believed to originate in supernova explosions and pulsars. Their relative abundances, and the ratios of their isotopes, provide information on the conditions existing at the time of their formation, their ages, and the conditions they encountered on their journey to Earth. Thus, the two HEAO 3 cosmic ray instruments

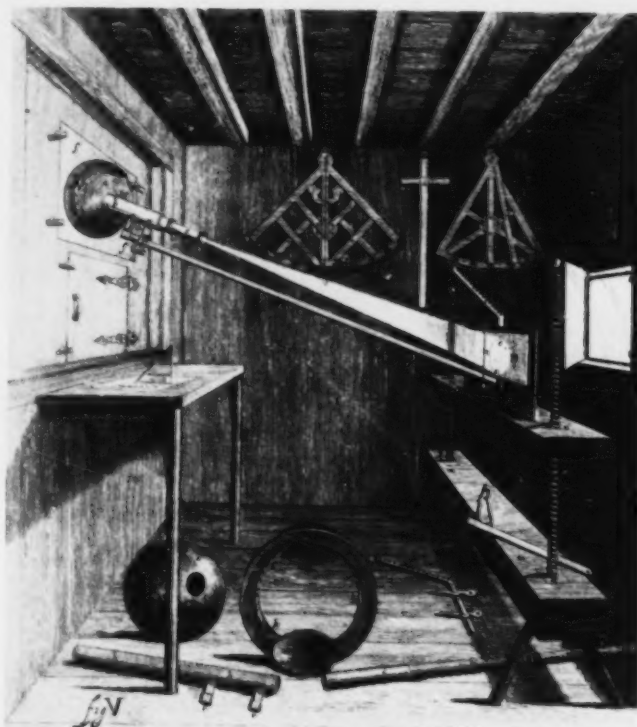
are providing valuable new information on the high energy processes that created these "cosmic messengers."

The HEAO 3 cosmic gamma ray spectrometer carried out an exploratory survey of the sky for gamma ray "line emission." Strong gamma ray emission was detected from major features along the galactic plane, such as the Crab Nebula, Cygnus X-1 and Centaurus A.

Liftoff of HEAO-3 aboard an Atlas-Centaur launch vehicle on September 20, 1979 at the Eastern Test Range, Cape Canaveral, Florida.







Andromeda spiral galaxy as seen through an optical telescope.

GLOSSARY

X-ray

Electromagnetic radiation in the energy band roughly between 100 electron volts and a few hundred thousand electron volts

Photon

A tiny bundle of radiant energy used as the fundamental unit of electromagnetic radiation

Cosmic Ray

An atomic nucleus stripped of its electrons and accelerated through space

Neutron Star

A collapsed star in which all matter has been reduced to neutrons

Pulsar

Rotating neutron star observed at earth to turn "on" and "off" at intervals consistent with rate of rotation

Black Hole

The most complete state of stellar collapse in which all matter is crushed out of existence and gravitational forces prevent even photons from escaping

Bursts

X-ray sources that suddenly and dramatically increase in intensity and then subside

Diffuse

Background electromagnetic radiation that does not originate from objects such as stars and galaxies

Continuum

Electromagnetic radiation without discrete components such as emission or absorption lines

Synchrotron Radiation

Electromagnetic radiation generated by charged particles moving in a magnetic field

Globular Cluster

A collection of typically several hundred thousand stars gravitationally bound into a roughly spherical shape

Nebula

A thin, extended object in space such as a supernova remnant or a cloud of gas and dust

SAS

Small Astronomy Satellite

Uhura

The Swahili word for "freedom," chosen as the name for SAS-1 because it was launched from a Kenyan site on the anniversary of Kenya's independence

Ariel

A British X-ray satellite

Bremsstrahlung

Radiation produced when a charged particle is slowed by an electric field

Isotropic

In the context of electromagnetic radiation, equally intense in all directions of viewing

Notes:

(1) Stars are classified by temperature in types: O, B, A, F, G, K, M in order of descending temperature. They are also classified by metal content. Population I stars have high metal content and Population II stars have low metal content.



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